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The effect of tempering temperature on the fatigue crack propagation rate (FCPR) in the low stress intensity range of HY130 austenitized at 815°C was determined. Four treatments giving the same hardness, R.C. 34, were selected: A - 10 hrs at 400°C, B - 5 hrs at 550°C, C - 1 hr at 610°C and D - ½ hr at 650°C. Treatment C, the standard treatment for HY130, gave the highest value of stress intensity threshold, ΔK_{th}, and the lowest propagation rate at ΔK of 5 MPa√m. For HY80 intercritical heat treatments were developed to give desired distributions of ferrite and martensite for measurement of ΔK_{th}.

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DEPARTMENT OF MATERIALS SCIENCE & ENGINEERING
THE TECHNOLOGICAL INSTITUTE
NORTHWESTERN UNIVERSITY
EVANSTON, IL 60201

Annual Technical Report, 1 Sep 80-31 Aug 81

Thresholds for Fatigue Initiation and Propagation and Plastic Work in HY80 and HY130 Steels,

ONR Contract N00014-78-C-0565

For the Period

1 September 1980 to 31 August 1981

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INTRODUCTION

Decreasing the fatigue crack propagation rate of HY80 and HY130 steels would be expected to increase their applicability. In previous research in this laboratory, it has been shown that the fatigue crack propagation rate at intermediate stress intensities, ΔK, can be described by the approximate equation

$$\frac{da}{dN} = A \frac{(\Delta K)^4}{\mu \sigma_y'^2 U} .$$

In this equation, A is a universal dimensionless constant, μ is the shear modulus, σ_y' is the cyclic yield stress, and U is the plastic work per unit area of fatigue crack propagation which itself is a function of ΔK. A method for measuring U was developed whereby strain gages are cemented ahead of fatigue cracks and the stress-strain relations are recorded as the crack approaches. The previous reports[1] and papers[2,3] reported experimental verification of this equation for HY80 and HY130 steels. For low fatigue crack propagation rate at a given value of ΔK in the intermediate range, one needs to achieve large U without sacrificing σ_y'. Last year[1] we reported results for a series of tempering temperature-time combinations for HY130 which gave the same hardness values but much different microstructures; da/dN at constant mid-range ΔK was nearly the same for all combinations.

Since da/dN at low ΔKs is much more sensitive to microstructure, during the past year a comprehensive study of the effect of microstructure on da/dN in the near threshold region of ΔK was undertaken for HY80 and HY130. From a practical point of view, this region of ΔK is more important than the higher ΔK region; however, the theory is only in a primitive state.

Ritchie and others in studying quenched and tempered steels have shown that ΔK_{th} increases as the tempering temperature is increased and at the same time the yield strength is reduced. As described in last year's report, HY130 offers the opportunity to increase the tempering temperature without reducing strength because at the high tempering temperatures secondary hardening occurs with alloy carbides replacing Fe_3C. In HY80 dual phase microstructures are of particular interest because of the results of Suzuki and McEvily[4] for 1018 steel. A microstructure consisting of ferrite islands in martensite gave a very high ΔK_{th}.

EXPERIMENTAL DETAILS AND RESULTS

HY80 and HY130 of the following compositions, in weight percent, obtained from the U. S. Steel Research Laboratory, have been used for this research.

	C	Ni	Cr	Mo	Mn	V	Si
HY80	0.18	3.00	1.58	0.50	0.32	0.006	0.27
HY130	0.10	5.33	0.49	0.57	0.35	0.064	0.23

The standard heat treatment for HY130 is austenitizing at 815°C followed by tempering 1 hr at 610°C while HY80 is austenitizing at 900°C followed by tempering 1 hr at 700°C.

As described in last year's report, three additional tempering heat treatments (10 hrs, 400°C; 5 hrs, 550°C and ½ hr, 650°C) besides the standard one for HY130 were devised to give the same approximate hardness, 31-33 Rockwell C. The fatigue crack propagation measurements were performed on a closed loop MTS machine under load control using a sinusoidal wave of 30 Hz with R = 0.05 in center notch specimens.

The results at intermediate ΔKs in HY130 with these four heat treatments done in air and argon environments were reported last year. During the past year the tests were extended to the low ΔK region. The threshold ΔK was measured by the load shedding technique in dry argon environment. When da/dN is below 10^{-9} m/cycle the load reduction must be smaller than 5% to avoid crack arresting. After ΔK was decreased to where no crack growth was detected in 2×10^6 cycles, the load was increased to give a small increment of ΔK and da/dN was measured again.

The crack propagation rates near ΔK_{th} in HY130 with the different heat treatments are shown in Figs. 1-4. The intermediate ΔK data from the previous report are plotted in the same figures. The near threshold fatigue crack propagation results are summarized in the following table. The four sets of data are compared in Fig. 5.

Fatigue Crack Propagation Rate Data of HY130 for
Four Tempering Treatments

	Hardness (R.C. Scale)	ΔK_{th} (MPa $\sqrt{m}$)	da/dN (m/cycle) (at ΔK=5 MPa $\sqrt{m}$)	da/dN (m/cycle) (at ΔK=20 MPa $\sqrt{m}$)
A 10 hrs, 400° C	33	2.8	3×10^{-9}	4×10^{-8}
B 5 hrs, 550° C	33	3.0	2×10^{-9}	4×10^{-8}
C 1 hr, 610° C	33	3.6	1×10^{-9}	5×10^{-8}
D $\frac{1}{4}$ hr, 650° C	31	3.2	2×10^{-9}	5×10^{-8}

All done in dry argon

The standard treatment, tempering 1 hr at 610° C, gave the lowest da/dN at ΔK of 5 MPa $\sqrt{m}$ and highest ΔK_{th}, 3.6 MPa $\sqrt{m}$.

The previous da/dN data at intermediate ΔKs seems slightly lower than the present data. This may be partially explained by a difference in specimen thickness. For the low ΔK tests, wider and thicker specimens

were used. These give closer to plane strain conditions at intermediate ΔKs.

Scanning electron microscopy was used to examine the fracture surfaces near the threshold region. The scanning electron micrographs of the fatigue fracture surfaces of specimens tempered 1 hr at 610°C and 10 hrs at 400°C are shown in Figs. 6 and 7 respectively. In Fig. 6 the fracture morphology shows a ductile transgranular fracture mode to have occurred. The morphology is similar at intermediate ΔKs. While the fracture mode for 10 hrs at 400°C is also mostly transgranular, Fig. 7, there are some intergranular facets. The proportion of intergranular facets is reduced with increase in ΔK. The lower ΔK_{th} for this treatment seems to be due to the intergranular fracture mode. Its origin is not known.

In view of the high ΔK_{th} reported by Suzuki and McEvily[4] in dual phase ferrite-martensite 1018 steel, a considerable amount of effort was spent on developing heat treatments for producing martensite-ferrite structures in HY80. Based on extensive metallographic study, two types of inter-critical heat treatments were selected: (a) intermediate quench and (b) step quench. In the former, specimens are austenitized at 900°C for one hour, water quenched, reheated for variable times at 750°C and water quenched again. This results in a mixture of lamellar and equiaxed ferrite in a martensite matrix. The typical microstructure is shown in Fig. 8. The volume fraction of the lamellar ferrite decreases with time at 750°C. In the step quench treatment after austenitizing at 900°C, the specimen is cooled directly to 650°C, isothermally transformed and then water quenched. This results in equiaxed ferrite particles distributed in a martensite matrix. The micrograph of a specimen transformed

isothermally for 6 hrs at 650°C is shown in Fig. 9. The amount of ferrite increases with time at 650°C.

After these heat treatments the specimens appear banded. This is believed to result from structural inhomogeneities in the initial as received hot rolled steel. An initial heat treatment to form bainite seems to alleviate the banding. The plan is to completely eliminate the banding before measuring ΔK_{th} and da/dN versus ΔK in various dual phase HY80 structures.

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2. S. I. Kwun and M. E. Fine, "Fatigue Macrocrack Growth in Tempered HY80, HY130, and 4140 Steels: Threshold and Mid-ΔK Range", Fatigue of Engineering Materials and Structures 3, 367 (1980).

3. P. K. Liaw, S. I. Kwun and M. E. Fine, "Plastic Work of Fatigue Crack Propagation in Steels and Aluminum Alloys", Met. Trans. 12A, 49 (1981).

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PERSONNEL

Mr. Jain-Long Horng, Graduate Research Assistant 9/79 to present.

PUBLICATIONS

1. S. I. Kwun and M. E. Fine, "Fatigue Macrocrack Growth in Tempered HY80, HY130, and 4140 Steels: Threshold and Mid-ΔK Range", Fatigue of Engineering Materials and Structures 3, 367 (1980).

2. P. K. Liaw, S. I. Kwun and M. E. Fine, "Plastic Work of Fatigue Crack Propagation in Steels and Aluminum Alloys", Met. Trans. 12A, 49 (1981). Also supported by AFOSR.

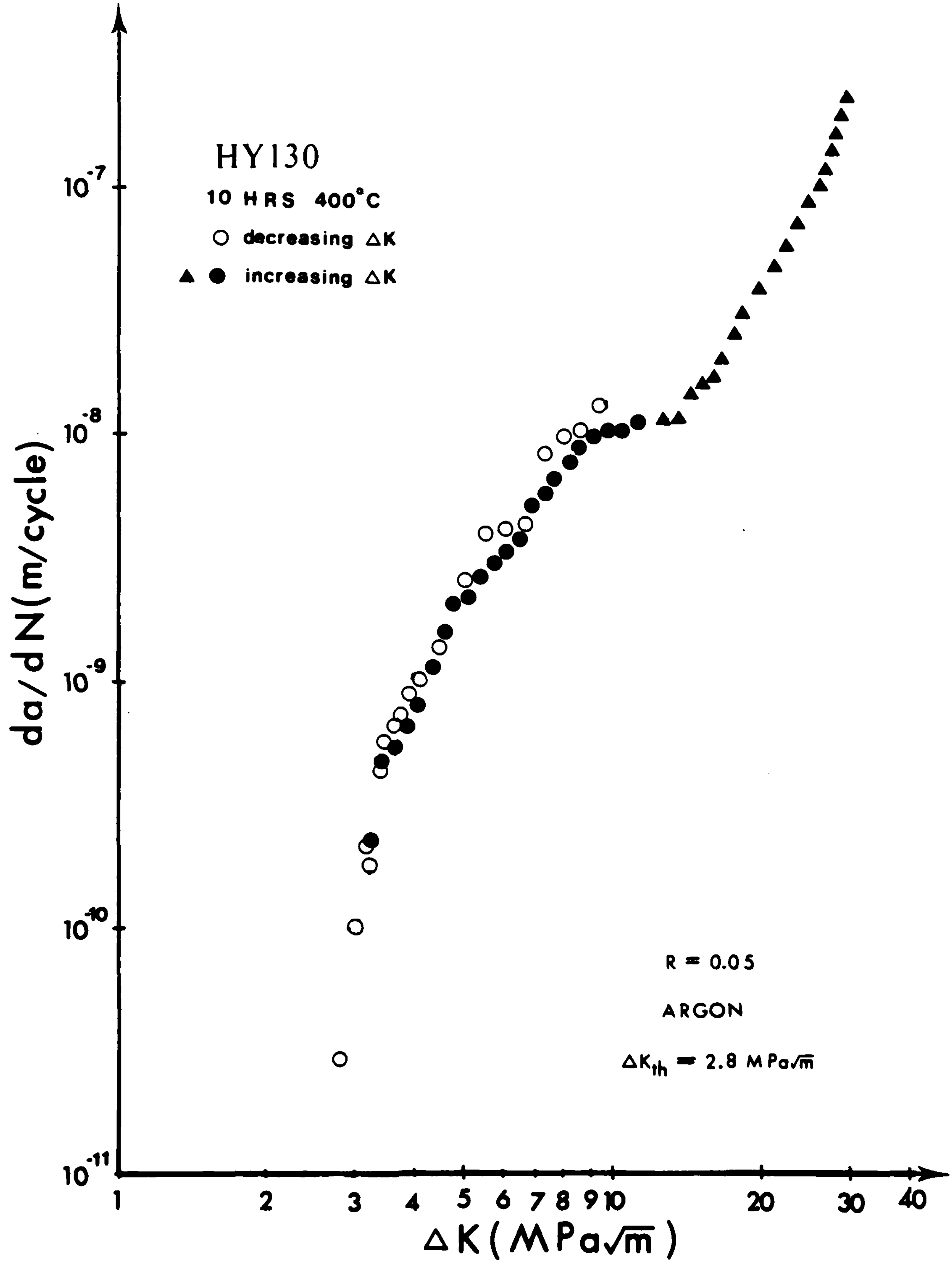

Fig. 1. Fatigue crack propagation rate versus ΔK of HY130 tempered 10 hrs at 400° C.

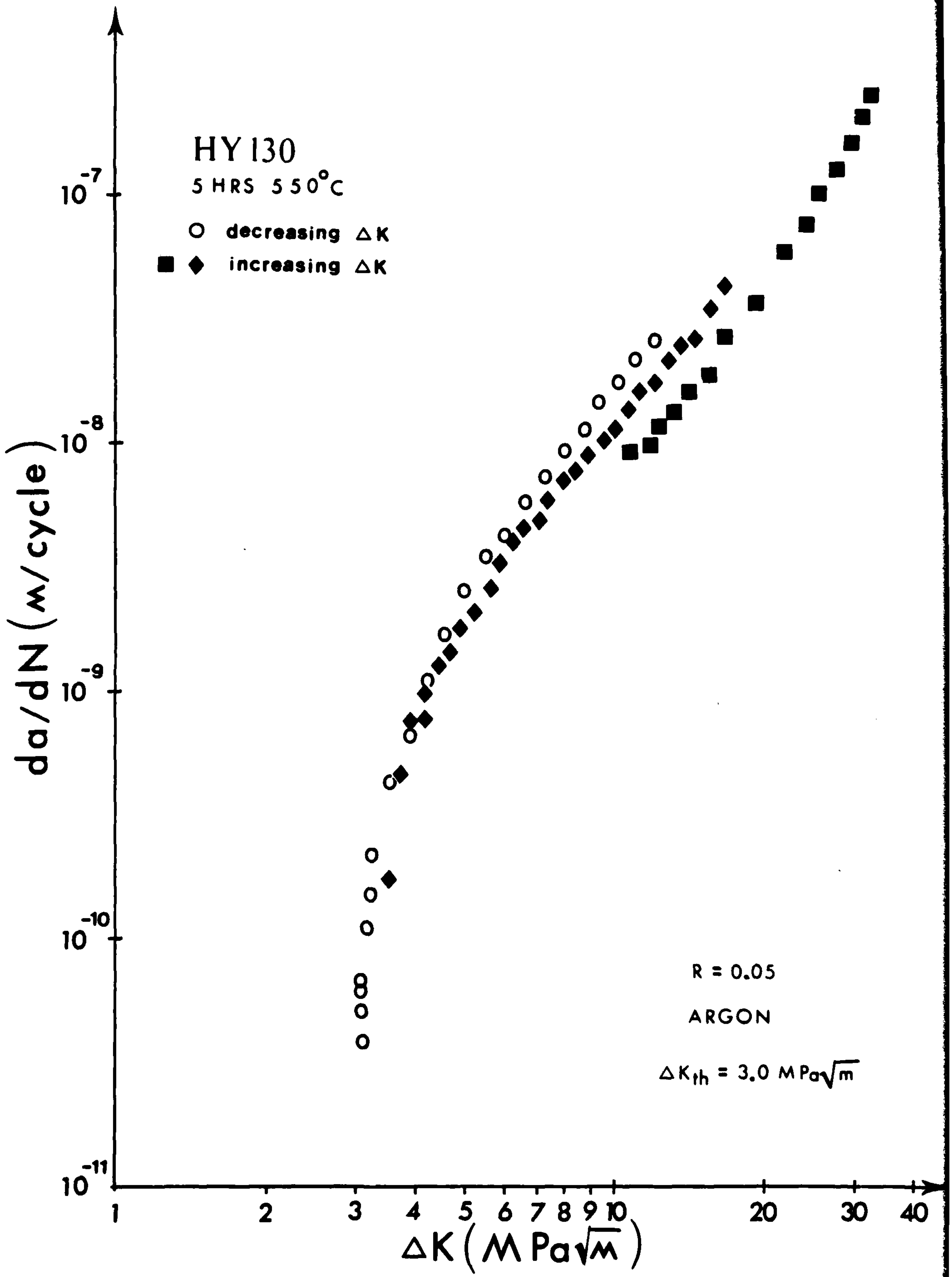

Fig. 2. Fatigue crack propagation rate versus ΔK of HY130 tempered 5 hrs at 550°C.

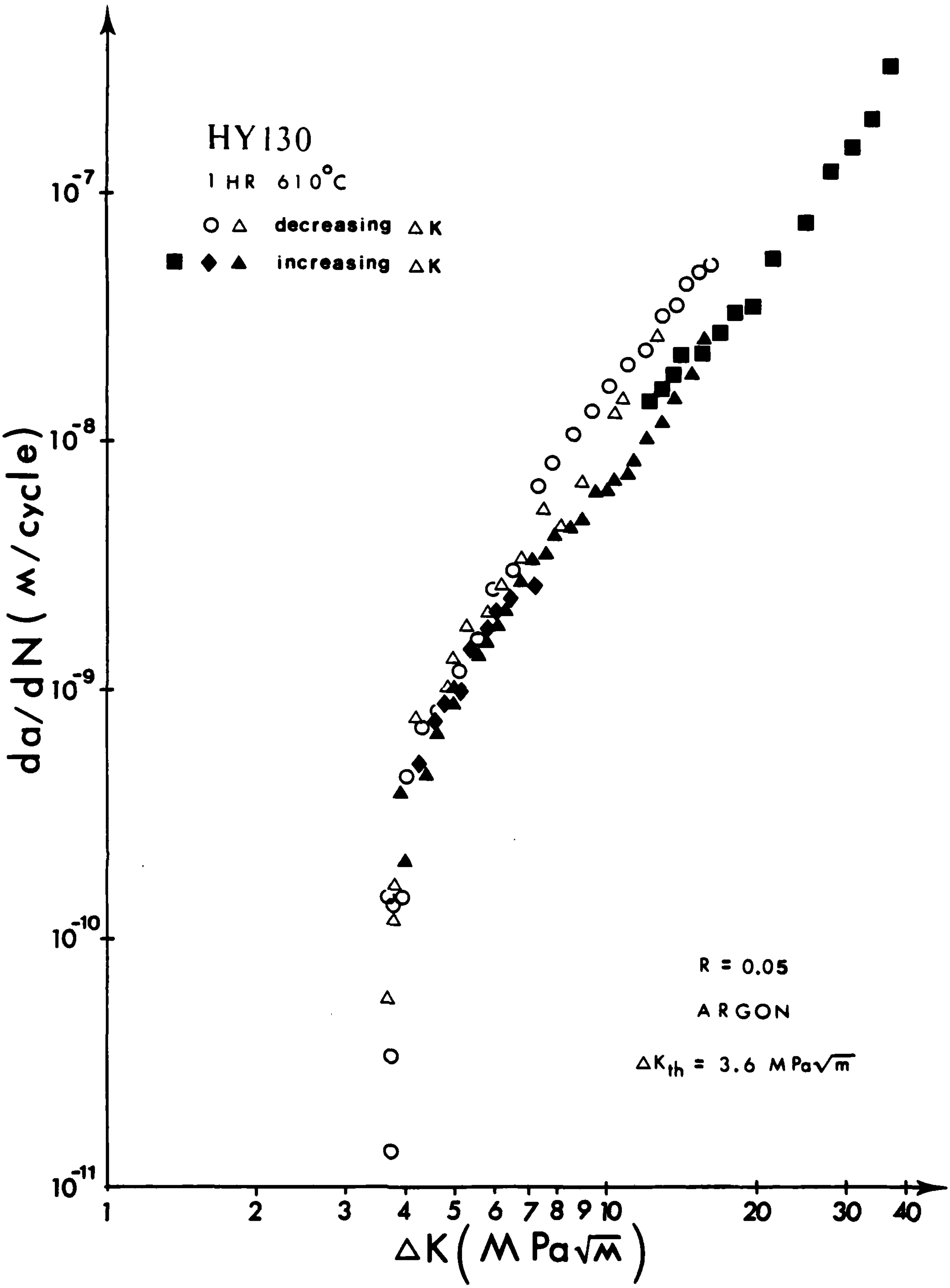

Fig. 3. Fatigue crack propagation rate versus ΔK of HY130 tempered 1 hr at 610°C.

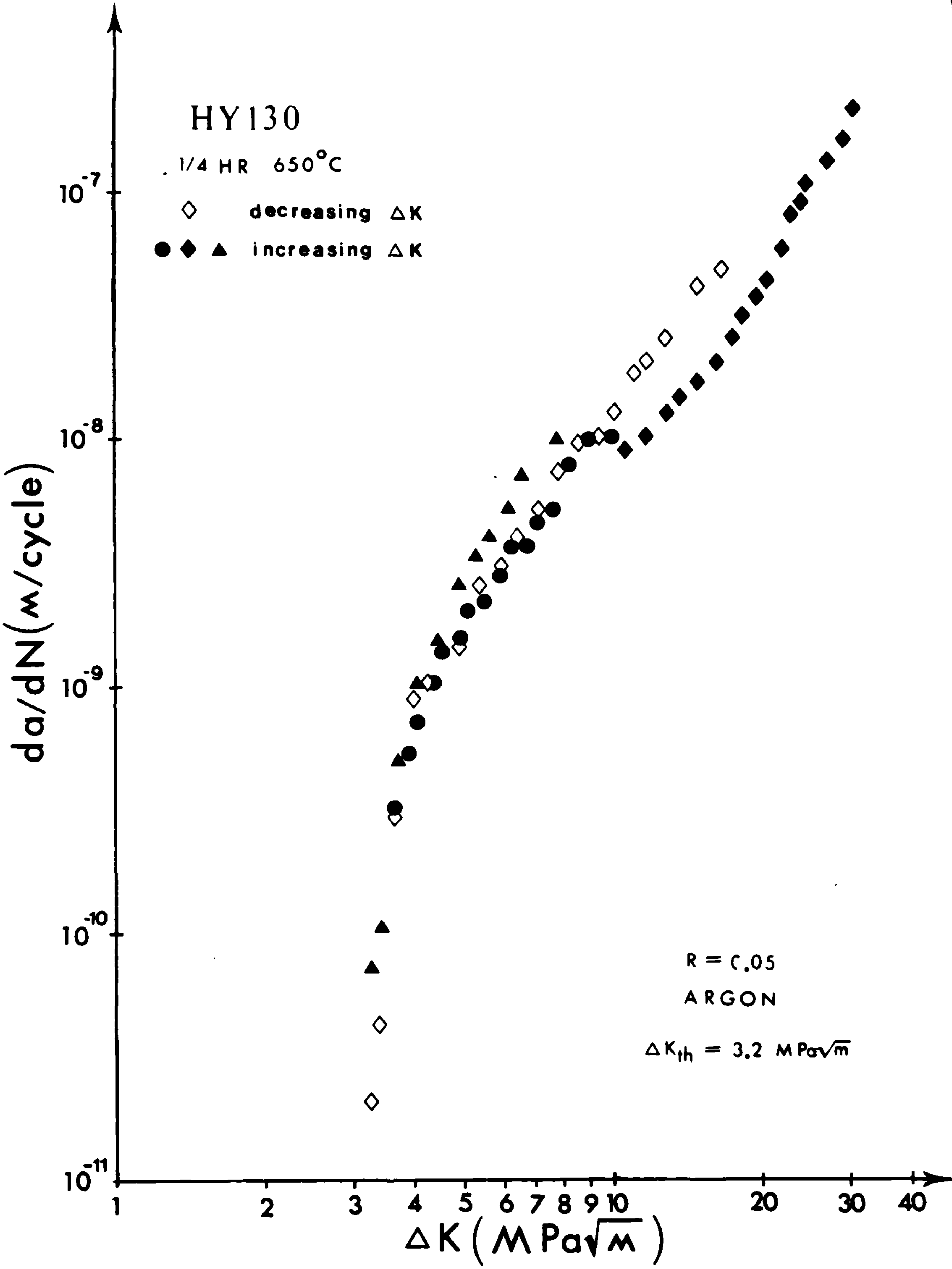

Fig. 4. Fatigue crack propagation rate versus ΔK of HY130 tempered ¼ hr at 650°C.

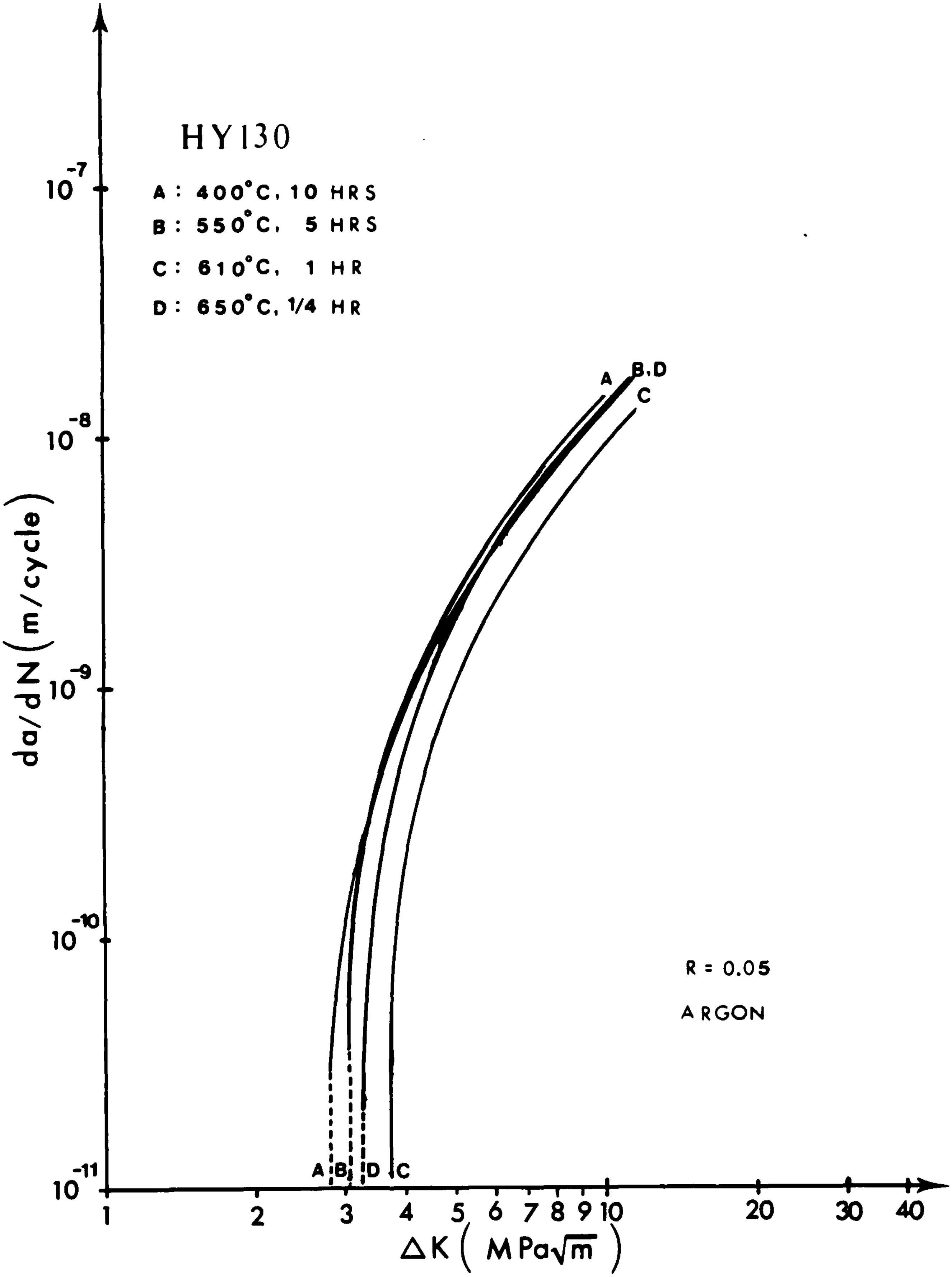

Fig. 5. Comparison of fatigue crack propagation rates of HY130 for the four tempering treatments.

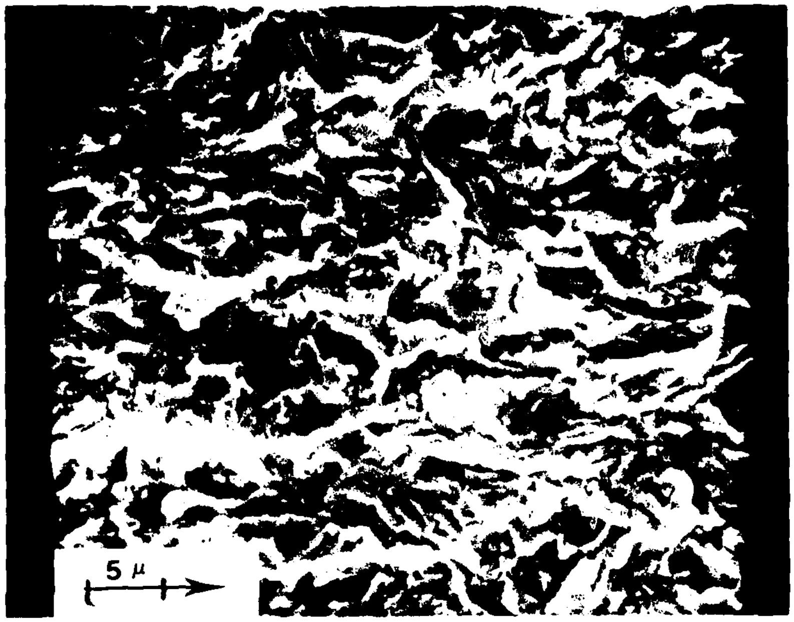

Fig. 6. Scanning electron micrograph of the fatigue fracture surfaces of HY130 tempered 1 hr at 610° near threshold region ($\Delta K \sim 4$ MPa$\sqrt{m}$). The arrow shows the direction of crack propagation.

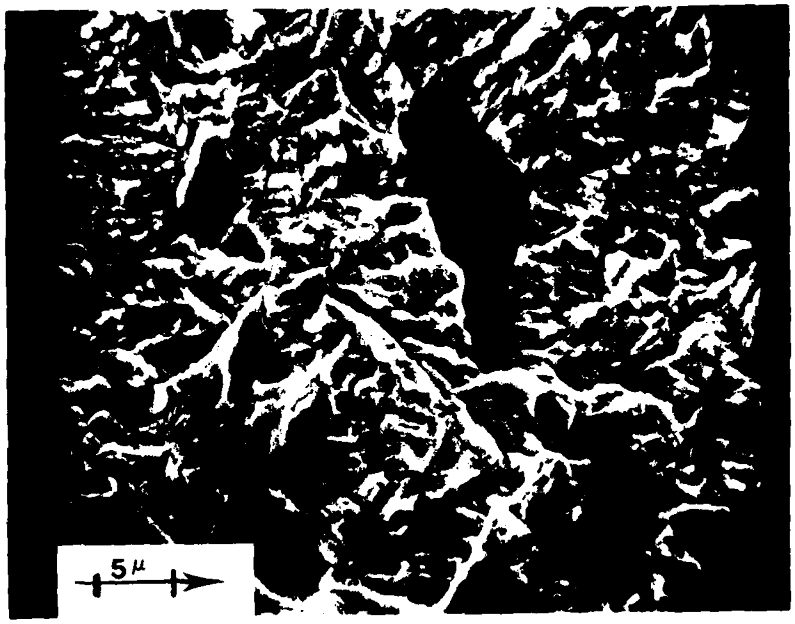

Fig. 7. Scanning electron micrograph of the fatigue fracture surfaces of HY130 tempered 10 hrs at 400° C near threshold region ($\Delta K \sim 3$ MPa$\sqrt{m}$). The arrow shows the direction of crack propagation.

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Fig. 8. Micrograph of dual phase of HY80 austenitized at 900° C for 1 hr, water quenched, reheated at 750° C 3 hrs and then water quenched.

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Fig. 9. Micrograph of dual phase of HY80 austenitized at 900° C for 1 hr, cooled directly to 650° C for 6 hrs and then water quenched.